RECENT GEOLOGICAL HISTORY OF THE TIMBALIER BAY AREA AND ADJACENT CONTINENTAL SHELF

by James P. Morgan

ABSTRACT

The basic outlines of Timbalier Bay and the adjacent continental shelf were sketched at the close of the last Ice Age, approximately 3600 years ago. Since then, the area has been shaped and changed by three major processes: river deposition, sea level fluctuation, and land variation. Sedimentation from the Mississippi River has caused the deltaic plain to prograde seaward, while a rise in sea level and land subsidence have caused a general inundation of areas that were, until very recently, dry land.

INTRODUCTION

To comprehend the complex and changing environment of the central Louisiana continental shelf and adjacent beaches, bays, and marshlands, it is necessary to consider the geological development of this region during the Holocene, or Recent epoch. This latest geological episode is generally thought to span the past 16,000 to 18,000 years, an interval of ameliorating climate following the last of the glacial ages.

During the last few thousand years of the Holocene, approximately one-third of Louisiana's present land area was fashioned by a series of highly dynamic geological processes. Although the processes are numerous and complex, there are three dominant and interrelated aspects to be considered: (a) deltaic sedimentation by the Mississippi River, (b)

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sea-level fluctuations (mainly rise), and (c) land-level variations (principally subsidence). The Gulf of Mexico surface establishes the base level of the Mississippi River, as well as that of other streams. Base level also controls deltaic sedimentation. Therefore, fluctuations of land level relative to water level significantly influence sedimentation and must be considered in addition to the depositional processes themselves.

SEA-LEVEL VARIATIONS

At the culmination of the last ice age, glacial ice covered approximately 15,000,000 square miles of the earth's polar and mountainous continental land areas. During the subsequent 17,000 or so years, most of this ice melted, until at present less than 6,000,000 square miles of land are ice covered. The melt waters returned to their source, and sea level rose some 400 feet during the same period (see figure 1). Glacial melting was rapid at first and produced rapid sea-level rise, but the rates diminished significantly during the past 7000 years (Curray 1965).

Scientists disagree on the details of sea-level fluctuations during these last few thousand years, and definitive work remains to be done. In general, however, three different interpretations have been presented: (a) a continuous, slow rise of sea level for the past several thousand years; (b) a rise until approximately the present level was reached some 3600 to 5000 years ago, with essential stability since that time; and (c) continuing rise until about 6000 years ago to a few feet higher than at present, followed by a minor fall to the present level. Though I will not evaluate the details here, the second of the concepts above seems best to fit the facts known for Louisiana (Coleman 1966). Sea-level rise seems to have

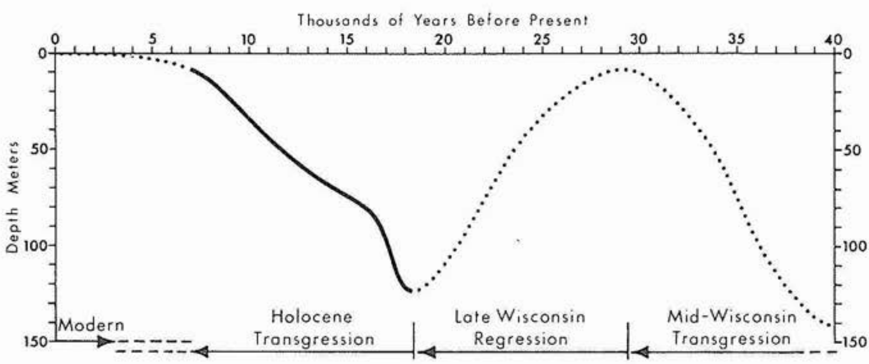

FIG. 1. GENERALIZED CURVE OF LATE QUATERNARY SEA-LEVEL FLUCTUATIONS. Modified from Curray (1965).

continued at a decelerating rate until about 3600 years ago, at which time it reached its present level. Subsequently, there seem to have been only minor fluctuations of a foot or so.

Precise data on sea-level variations are furnished by continuously recording tide gauges that are maintained at many seaports around the world. Since accurate gauging has been technically possible for less than a hundred years, reliable data are available only for a relatively short interval. For example, the first tide gauge established in the Gulf of Mexico (at Galveston, Texas) has been in operation only since 1909 (figure 2). In this relatively short time, the gauge reveals an overall sea-level rise of more than one foot. The curve shows a considerable variation in level from year to year and the "average" or "mean sea level" curve can be drawn and interpreted in various ways.

Furthermore, such a gauge, mounted on pilings, records not only rise of sea level but also subsidence of the underlying land. It is very difficult to separate these two processes that have the same end result. Whatever its cause, the "relative" sea-level rise at the Galveston gauge means that there has been a resulting inundation of low-lying lands by the sea, an event that geologists call "marine transgression." Such transgressions result in ecological changes: sea water replaces fresh water, with resulting effects on the fauna and flora that inhabit the area.

Although a one-foot sea-level rise hardly constitutes a major marine transgression, in the low marshlands of Terrebonne and Lafourche

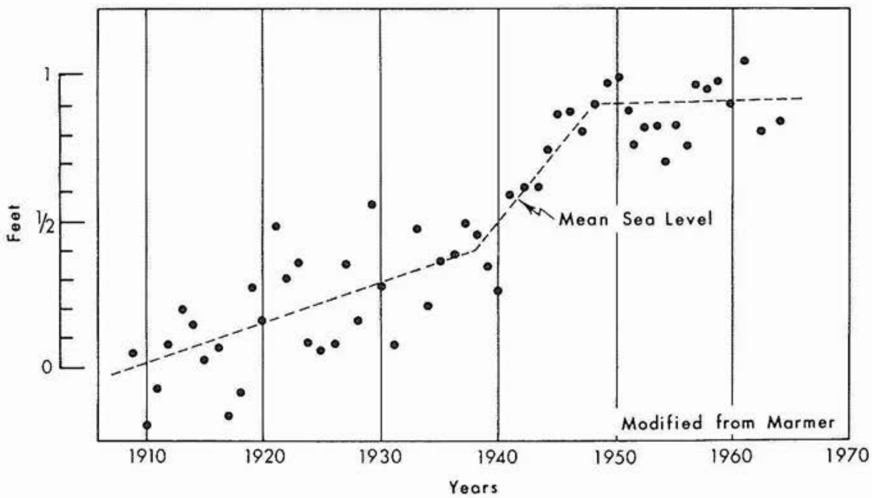

FIG. 2. SEA-LEVEL VARIATIONS AT GALVESTON, TEXAS. Modified from Marmer (1952).

parishes, many hundreds of square miles have been influenced. These natural changes have taken place concurrently with a growing human use of the marshlands for trapping, commercial and pleasure boating, and especially the search for and exploitation of petroleum, natural gas, sulfur, and salt. It becomes very difficult to separate the changes caused by the minor marine transgression from those related to man's alteration of the marshlands.

In contrast to the minor sea-level rise recorded during the past 75 to 100 years, there has been a major marine transgression since the end of the last ice age. The rise, more than 400 feet, caused the shoreline to move from approximately the continental shelf edge to its present position, a distance of as much as 140 miles in western Louisiana (figure 3). Numerous transgressive shoreline features were left on the inundated continental shelf as sea level rose. Elongate, sandy deposits, such as Ship Shoal, 10 to 15 miles seaward of Isles Dernieres (figure 3) still await study, but they probably represent beach deposits formed during minor cessations or changes in rate of sea-level rise (Fisk 1955).

Shallow borings in southwest coastal Louisiana reveal a series of peat deposits related to early Mississippi River deltaic deposition (Coleman 1966). These peat deposits have been radiocarbon dated and reveal various ages back to some 7200 years ago, when sea level stood about 25 feet lower than at present. From data such as these, it can be argued that the Mississippi deposited deltaic sediments at various places across the continental shelf during the post-glacial transgression. Details of these events are unknown, but it is quite possible that the Louisiana shelf is covered by a complex of deltaic deposits, as well as by reworked beach and near-shore features.

LAND-LEVEL VARIATIONS

The east-west-trending Louisiana coastline generally follows the axis of a downwarped section of the continental margin known as the "Gulf Coast geosyncline." Tens of thousands of feet of deltaic and shallow-marine sediments have accumulated in this subsiding trough during the past few tens of millions of years. (These Cenozoic-age sediments are the source beds for south Louisiana's rich petroleum accumulations.) The geosynclinal sediments reveal a nearly continuous record of basin subsidence contemporaneous with sediment deposition. Such subsidence continues to affect the Gulf Coastal Plain, but at rates that become significant only when considered in spans of many thousands of years.

A more significant, short-term factor is the localized subsidence that accompanies compaction and water expulsion from newly deposited

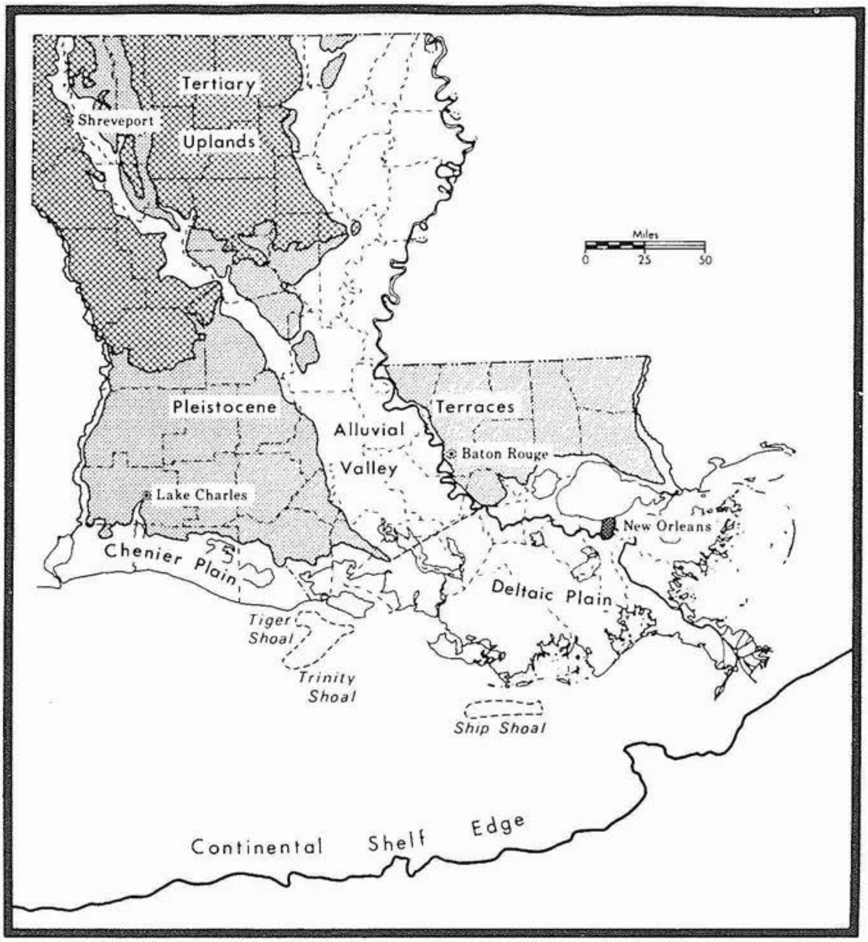

FIG. 3. PHYSIOGRAPHY AND GENERALIZED GEOLOGY OF THE LOUISIANA COASTAL PLAIN AND SHELF.

sediments. The significance of this compaction can be seen in its influence on the materials dumped rapidly by the Mississippi in fashioning its delta. Precise measurements are difficult, but sediment compaction in the delta vicinity has lowered the surface at rates ranging from 1.3 to 4.3 cm per year (Swanson and Thurlow 1973). Such subsidence rates reflect compaction and water expulsion from the recently deposited sediment. Compaction, in turn, is determined by the nature of the sedimentary particles and by the amount of water contained in the spaces between the particles.

The Mississippi delta sediments, like those of most deltas, vary greatly both horizontally and vertically in particle size. They are composed dominantly of clay and silt-sized particles, with only a small percentage of fine and very fine sand. The clays contain a large quantity of water, both attached to and trapped between the flake- or sheet-like clay particles. Clay deposits yield this water slowly but continuously under compaction. Silts and sands behave differently from clays in that individual particles are more nearly spherical, with water confined to the voids between particles. Under compaction, this water is expelled until the individual sediment grains are in physical contact, at which time compaction virtually ceases. Hence, deposits containing significant fractions of clay subside under compaction for longer periods, but sandy strata compact rapidly. Thus, variable subsidence rates reflect, among other factors, local variation in sediment type deposited by the river.

DELTAIC SEDIMENTATION—MISSISSIPPI RIVER

Depositional processes

Rapid sea-level rise and resultant marine transgression typified the early part of the Holocene. Some 7000 years ago, the rate of rise began to slow, and depositional processes by the Mississippi River, previously overwhelmed, became more prevalent. A number of deltaic depositional sites developed on the continental shelf, only to be abandoned and subsequently inundated by the rising Gulf of Mexico. About 5000 years ago, the river discharged its sedimentary load in central coastal Louisiana and fashioned a broad, delta-shaped mass, known as the "Sale-Cypremort delta" (figure 4). Gulf level at that time was apparently still some 8 to 12 feet lower than at present. Following abandonment of the Sale-Cypremort delta in favor of a depositional center farther east, the Sale-Cypremort sedimentary mass was reworked by the still-rising sea, leaving Tiger and Trinity shoals as remnants (see figure 3).

About 3600 years ago, as the Gulf reached its still-stand position, the episode of eustatic sea-level rise virtually ceased. River deposition subsequently became the dominant process and has fashioned a broad deltaic plain in southeastern Louisiana (see figure 4).

Cyclical deltaic sedimentation by the Mississippi River has been rather thoroughly described (Scruton 1960; Coleman and Gagliano 1964; Morgan 1970) and can be briefly summarized for the central coastal area as follows: On reaching the Gulf (base level), an alluviating river, such as the Mississippi, is forced to deposit its entrained sedimentary load because its flow-velocity diminishes. Resulting sedimentary deposits accumulate,

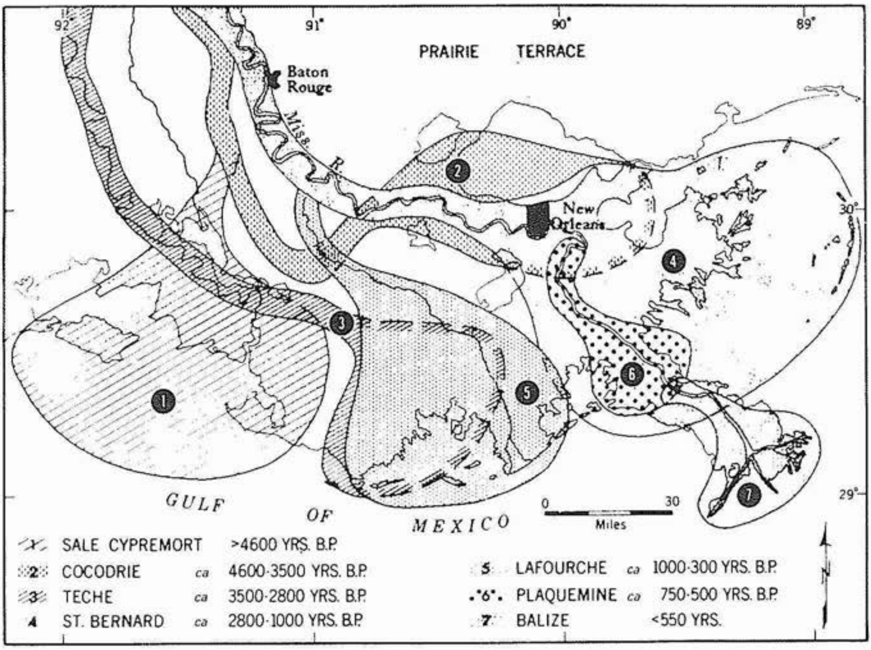

FIG. 4. CHRONOLOGY OF DELTAS THAT COMPOSE THE HOLOCENE MISSISSIPPI RIVER DELTAIC PLAIN. Modified from Kolb and Van Lopik (1958).

forming a delta and gradually building seaward (prograding). The river branches time and again to form an anastomosing, radiating pattern typical of deltaic distributaries. As each distributary lengthens, its gradient diminishes, and the channel becomes increasingly inefficient. The deltaic distributaries ultimately cannot handle their water and sediment loads, and the river is forced to divert through a new distributary that has a shorter route (and steeper gradient) to base level. During the past several thousand years, this sequence has recurred several times, with the result that the river has fashioned its deltaic plain from a number of overlapping deltaic lobes (see figure 4). Subsidence, mainly compaction of soft, newly deposited sediments, has allowed later delta lobes to prograde across and over older sequences.

Details are increasingly vague for the progressively older delta lobes; however, a study of the modern delta reveals a series of smaller subdeltas surrounding and peripheral to the major delta framework (figure 5). These details of subdeltaic development during the past three centuries are revealed by comparisons of old maps. It can be assumed with consid-

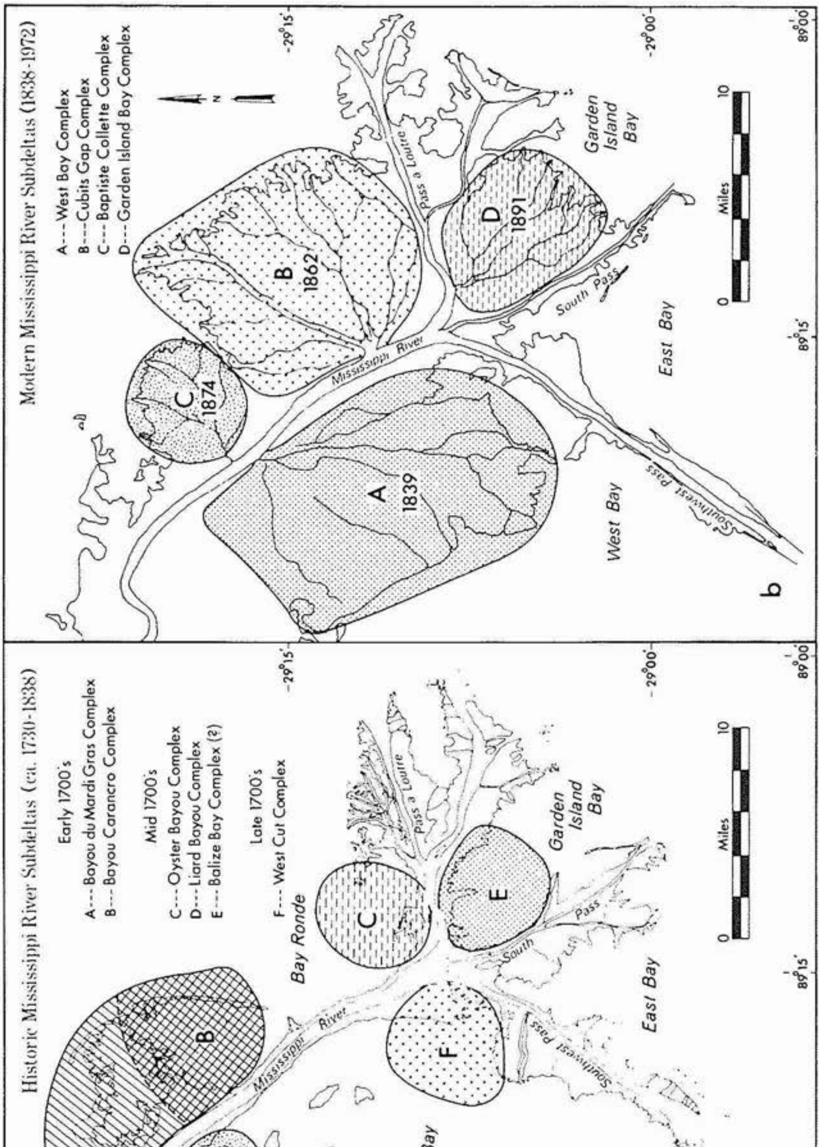

FIG. 5. SUBDELTAS OF THE MISSISSIPPI RIVER. (a) approximate ages of earlier subdeltas. (b) modern subdeltas, showing dates of initial crevasses. After D. J. Morgan (1977).

erable certainty that similar subdeltaic development occurred during deposition of the earlier delta masses.

Early Lafourche Delta

The central Louisiana coast of Terrebonne and Lafourche parishes displays a distinctive pattern of deltaic distributary levees and flanking marshes, numerous ponds, lakes, and bays lying between their radiating channels (figure 6). Radiocarbon dating suggests that this delta formed during the period from 1000 to 300 years ago, although some distributaries no doubt had entered the area a few hundred years earlier, and the last active channel, Bayou Lafourche, carried flow until it was dammed off in 1906. The Lafourche system formed a very extensive delta in a relatively short period of time because it built seaward into quite shallow water left by the subsidence of the older Teche-Mississippi delta (see figure 4).

Insufficient data are available to reconstruct a detailed history of the Lafourche delta, but it certainly formed in at least two episodes, referred to for simplicity as "Early" and "Late." Distributaries of the Early Lafourche subdelta extended in a southerly direction from a point of breakup (analogous to present-day Head of Passes) at the site of the present town of Thibodaux (see figure 6). Bayous Little Black, Terrebonne, and Blue were the principal distributaries, with lower Bayou Lafourche at that time being either of lesser importance or nonexistent. These distributaries branched again near the present town of Houma to form a rather densely radiating network consisting of Bayous Black, Mauvais Bois, du Large, Grand Caillou, Petit Caillou, Terrebonne, Pointe au Chien, and Blue. Older Bayou Teche levees in the vicinity of Houma probably created a topographic barrier that, when finally breached, determined the positions of the numerous radiating deltaic distributaries.

A half dozen of the major distributaries branched again and again as they prograded seaward, forming a truly Δ-shaped land mass that extended a mile or so seaward of the trend of present-day Isles Dernieres. These distributaries apparently became so overextended that inefficient gradients resulted in the gradual diversion of the majority of the Lafourche-Mississippi's flow to the present course of Bayou Lafourche. As the numerous distributaries of the Early Lafourche delta were gradually deprived of their flow and sediment load by this diversion, marine processes became increasingly dominant. Attack by waves and marine currents winnowed the silts and clays from the deltaic deposits, concentrating the coarser materials (fine sands) in an elongated barrier-beach complex including Isles Dernieres, Wine, Caillou, Brush, and Casse Tete islands (see figure 6).

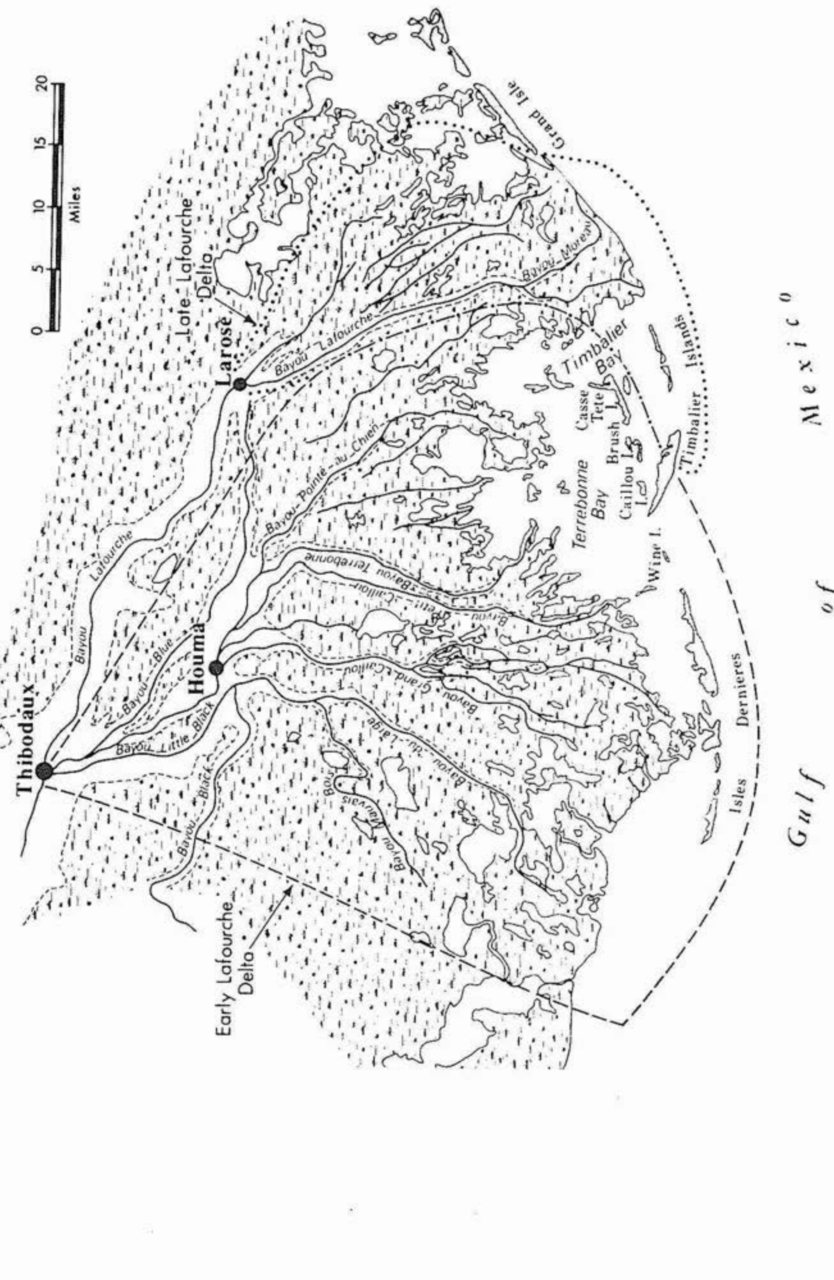

FIG. 6. THE LAFOURCHE-MISSISSIPPI RIVER DELTA, Terrebonne and Lafourche parishes, Louisiana.

With abandonment, sediment deposition diminished but subsidence through compaction continued. For a while, marsh growth was able to keep pace with subsidence, but interdistributary marshes were ultimately destroyed by enlarging ponds, lakes, and bays during this "destructional phase" of the deltaic cycle (Morgan 1973).

Late Lafourche Delta

Diversion from the Early to the Late Lafourche system probably was not a sudden event but one that required a hundred years or so (Fisk 1952). As Bayou Lafourche received an increasing volume of water and sediment, it prograded rapidly and built at least one major subdelta to the southeast of the present town of Larose (see figure 6). In its final phase of progradation, Bayou Lafourche and its principal distributary, Bayou Moreau, extended seaward, well beyond the destructional barrier island shoreline of the Early Lafourche system.

Diversion of the Mississippi from the Late Lafourche subdelta to its modern site took place several hundred years ago, and by the time of earliest historical records and maps, the Late Lafourche system was well into its destructional phase. Wave attack on the distributaries and marshes of Bayous Moreau and Lafourche caused rapid shoreline retreat, and the coarser fractions (fine and very fine sands) were concentrated to form the forerunners of Timbalier Island. Map comparison reveals that shorelines near the mouth of Bayou Lafourche were retreating rapidly during the last half of the nineteenth century. Retreat rates of more than 50 feet per year reflect the rapidity of subsidence and the consequent marine transgression (Morgan and Larimore 1957). The process has continued during the twentieth century, a result not only of continuing compaction and subsidence but also of sea-level rise. While Timbalier Island has retreated landward under wave attack, it has also migrated westward under the influence of the prevailing littoral currents. During a period of 116 years, the west end of Timbalier Island has moved northwestward about 4.25 miles, establishing a new shoreline trend seaward of the Caillou-Brush-Casse Tete island part of the Early Lafourche delta.

The earliest reasonably accurate maps of Terrebonne and Lafourche parishes were the township plats made during the 1830s and 1840s. These rather crude township surveys, augmented by other data, were compiled and included as part of the "Map of the Alluvial Valley of the Mississippi River" published in 1887 by the U.S. Army Corps of Engineers (figure 7). Configurations shown on this map indicate more the form of the coast during the earlier part of the nineteenth century than that of the map publication date.

In the intervening century or so, not only has the Timbalier-

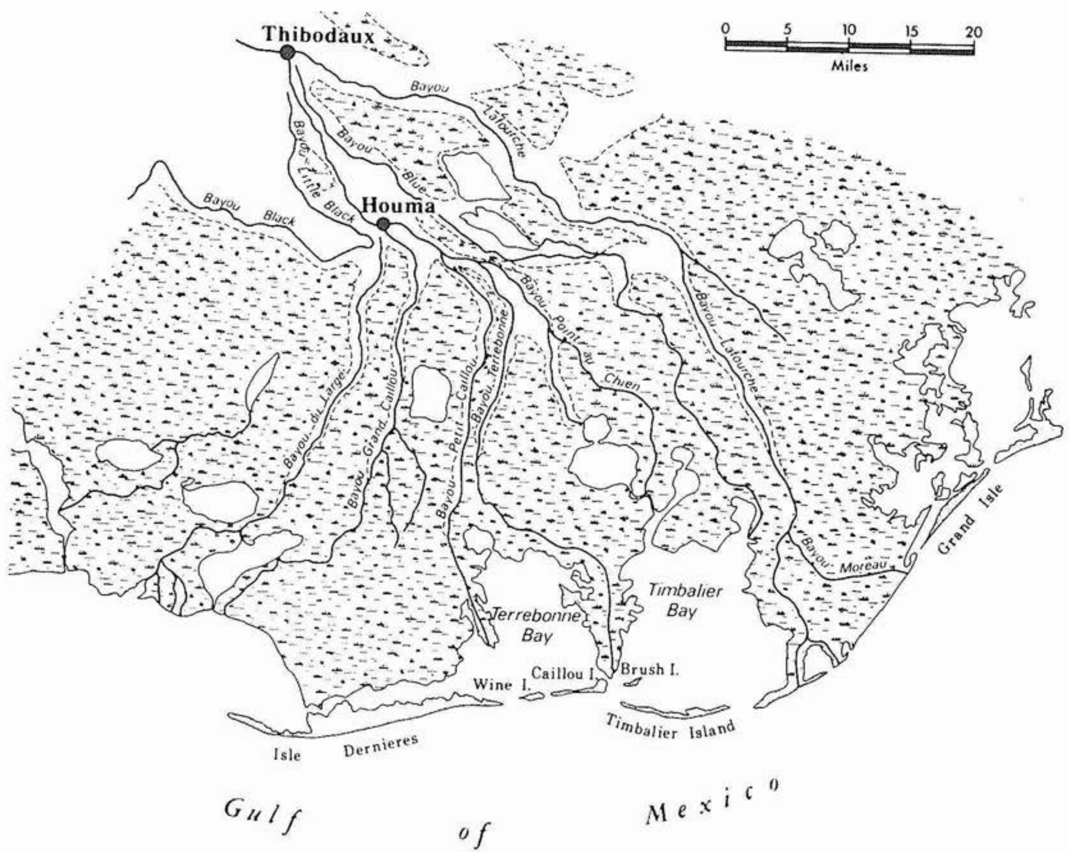

FIG. 7. THE LAFOURCHE-MISSISSIPPI DELTA as depicted on the "Map of the Alluvial Valley of the Mississippi River, 1887," U.S. Army Corps of Engineers, which was based on surveys made several decades earlier.

Dernieres Islands complex migrated northwestward in dramatic fashion, but there have been equally significant changes within the coastal bays (figures 6 and 7). Subsidence and erosion have removed surface expression of the seaward extension of Bayou Terrebonne, thereby allowing Timbalier and Terrebonne Bays to merge. Formerly extensive marshlands have deteriorated, to leave only scattered small islands throughout the rapidly enlarging bay.

Post-Deltaic history

Mississippi floods through the Bayou Lafourche distributary ended finally in 1906 with the construction of a permanent dam at its head at Donaldsonville. A small amount of river water has subsequently been pumped into the distributary to allow some flushing action. Following the disastrous flood of 1927, artificial-levee improvement on the lower Mississippi precluded further overbank flooding. Since that time, the Lafourche delta complex has been completely deprived of fresh water, except for local rainfall. Consequently, destructional processes have dominated the Lafourche delta for the past fifty years. Continuing subsidence has caused the radiating framework of distributary levees gradually to become reduced in height, length, and width. Interdistributary marshes have opened up, becoming ponds, lakes, and bays. As water bodies enlarged under wave attack, they also deepened.

Near the coast, a slowly growing network of tidal channels allows increasing brackishness in the interdistributary basins; flora and fauna change accordingly. The brackish-water clam *(Rangia cuneata)* and brackish-saline oyster *(Crassostrea virginica)* thrive in the delta-margin bays, and their shells become a major component in the bay-bottom sediments. To a lesser degree, other brackish-to-saline organisms also contribute to the sediments in the bays and lakes.

During the Lafourche-Mississippi's destructional phase, its deltaic sediments are rapidly being reworked and modified. Much of the reworking results naturally from more effective wave erosion, stemming from increased fetch and greater wave size, as well as the influence of tidal currents. Interdistributary marshes, attacked by these waves and currents, add their highly organic clays to the materials flooring the lakes and bays. In addition, some of the coarser-grained deltaic sediments, reworked by Gulf waves, are transported by currents into the more seaward parts of the bays.

HUMAN INFLUENCE IN THE LAFOURCHE DELTA

In addition to the essentially natural deltaic destructional processes previously described, man plays an increasingly dominant role in causing changes within the abandoned Lafourche delta. Most environmentally significant human activities within this marginal environment result in changes that parallel or accelerate natural processes. Hence, they are exceedingly difficult to document and, especially, to quantify.

For example, canalization increases water-exchange rates, which almost invariably lead to some degree of salt water intrusion toward the interior, with resultant changes in the flora and fauna. These modifications parallel those resulting from natural marine transgression, and it is very difficult to determine the proportional influence of each set of factors.

Boat traffic and shrimp trawling likewise play definite but poorly assessed roles in increasing water turbidity, with resulting detrimental effects on much of the flora and fauna. The results cannot be easily differentiated from discharge of oil-well cuttings or, for that matter, the bottom-stirring action of storm waves or abnormal tidal currents.

Detrimental influences of these activities—dredging, boat traffic, shrimp trawling, and discharge of cuttings or effluents—are greater within the bays than offshore. Shallow water depths and restricted circulation within the shallow bays and estuaries make those areas more susceptible to human influences than is the adjacent continental shelf, where more effective circulation patterns prevail.

To prevent or reduce adverse effects of human activities within the delta plain and adjacent shelf, it is necessary to understand in detail the physical, chemical, and biological characteristics influencing the two areas. Only when adequate scientific data are accumulated and evaluated will it become possible to assign environmental changes to human or natural influences.

NOTE

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